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DCF-1862

UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICE

TRENDS OF THE VOLATILE CONTENT (PARTICULARLY MOISTURE) OF  
EVERGREEN FOLIAGE DURING PERIODS OF DROUGHT STRESS

By

C. A. Connaughton and T. E. Maki  
Intermountain Forest and Range Experiment Station

June 10, 1935



DIRECTOR,  
Northern Rocky Mountain Forest  
and Range Experiment Station,  
MISSOULA, MONTANA

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This study of trends in the volatile content of evergreen foliage during periods of drought stress is a direct outgrowth of an investigation undertaken to ascertain conditions associated with extreme fire hazard in the ponderosa pine (Pinus ponderosa) forests of central Idaho. During years of protracted drought which occur at irregular intervals in this region, forest fires have been observed to spread with such unusual rapidity that the fuels in the forest have often been designated as being in an "explosive" condition. While the factors associated with "explosiveness" have not been fully understood, it has been assumed that the low moisture content of fuels combined with possible chemical changes, such as variations in volatile oil constituents, in coniferous needles, induces extreme inflammability. Since the forests of central Idaho are composed largely of evergreen conifers and the foliage of these trees makes up a large percentage of the forest fuels, it appeared that a study of the seasonal trends in the moisture content and other volatile constituents of ponderosa pine foliage would be an important phase of the general problem.

There was very little past study upon which to base an investigation of this nature, and as a consequence the introductory work

has been more or less preliminary in character and the phenomena encountered are discussed largely from a theoretical standpoint. The investigation as reported herein, has not progressed to a point where the general problem is solved even partially, yet the initial observations which were made in the course of the first year's study merit immediate consideration and disclose a broad field for future research.

#### Experimental Procedure

The study reported herein was conducted on two areas selected for the purpose of comparison, on the Boise Basin Experimental Forest in south-central Idaho. One area represented a young-growth stand of ponderosa pine timber about 60 years of age and the other, about 5 miles distant, represented a virgin stand of ponderosa pine timber about 250 years of age. At each location a series of normal, full-crowned dominant trees was selected on two sites, each site representing a distinct contrast in conditions to which growing trees are subjected. In the young-growth timber stand five trees were selected on an exposed south slope and five trees were selected in the bottom of a dry ravine. In the virgin timber stand five trees were selected on an exposed south slope and three trees were selected near a permanent stream, the contrast in regard to soil moisture being especially marked in this case. why only 3

Among other factors, soil temperature, soil depth, soil texture in lower horizons, and evaporation rate near the soil surface exhibited marked differences on each of the two sites in both the young-growth and virgin stands.

On the young-growth timber area, for example, the average soil temperature on the exposed south slope at a depth of 6 inches during August and September, was  $69.3^{\circ}$ , while the average soil temperature was  $53.4^{\circ}\text{F.}$  during the same period and under similar conditions in the bottom of the dry ravine. The hourly rates of evaporation at the two sites during the same period, as measured by the Livingston porous cup atmometers, were as follows:

Table 1. Young-growth area.

	South Slope	Ravine Bottom
	Cubic cm. per hour	Cubic cm. per hour
White bulb	1.88	1.18
Black bulb	2.35	1.32

Observations in regard to soil moisture showing the more arid conditions on the south slopes are shown in Figures X and Y presented later in the discussion.

A series of four branches on each tree, representing the upper and lower and north and south portion of the crowns, was selected and permanently marked, at the time the sample trees were designated. The north and south branches in the upper and lower portion of the crowns were confined to the same whorl insofar as possible. The number of twigs was recorded on each branch so that not more than 50 percent of the foliage would be removed during the course of the study. This avoided the possible effects of defoliation. Little precaution was necessary, however, since most of the branches had more than ample foliage.

Pertinent facts concerning the sample trees are contained in Table 2.

Table 2. Average size of sample trees and height of crowns and sample branches

Location	: Diameter of: : Tree Breast:	Total : Height:	: Length of: Crown	: Height of : Lower Sam-	: Height of : Upper Sam-
	: High	:	:	: ple Branches:	: ple Branches
	: Inches	: Feet	: Feet	: Feet	: Feet
Second growth area	:	:	:	:	:
South slope:	17.9	: 58	: 52	: 15	: 43
Dry ravine :	18.5	: 73	: 53	: 29	: 55
Virgin area :	:	:	:	:	:
South slope:	29.1	: 92	: 81	: 24	: 74
Creek bottom:	16.1	: 59	: 37	: 25	: 45

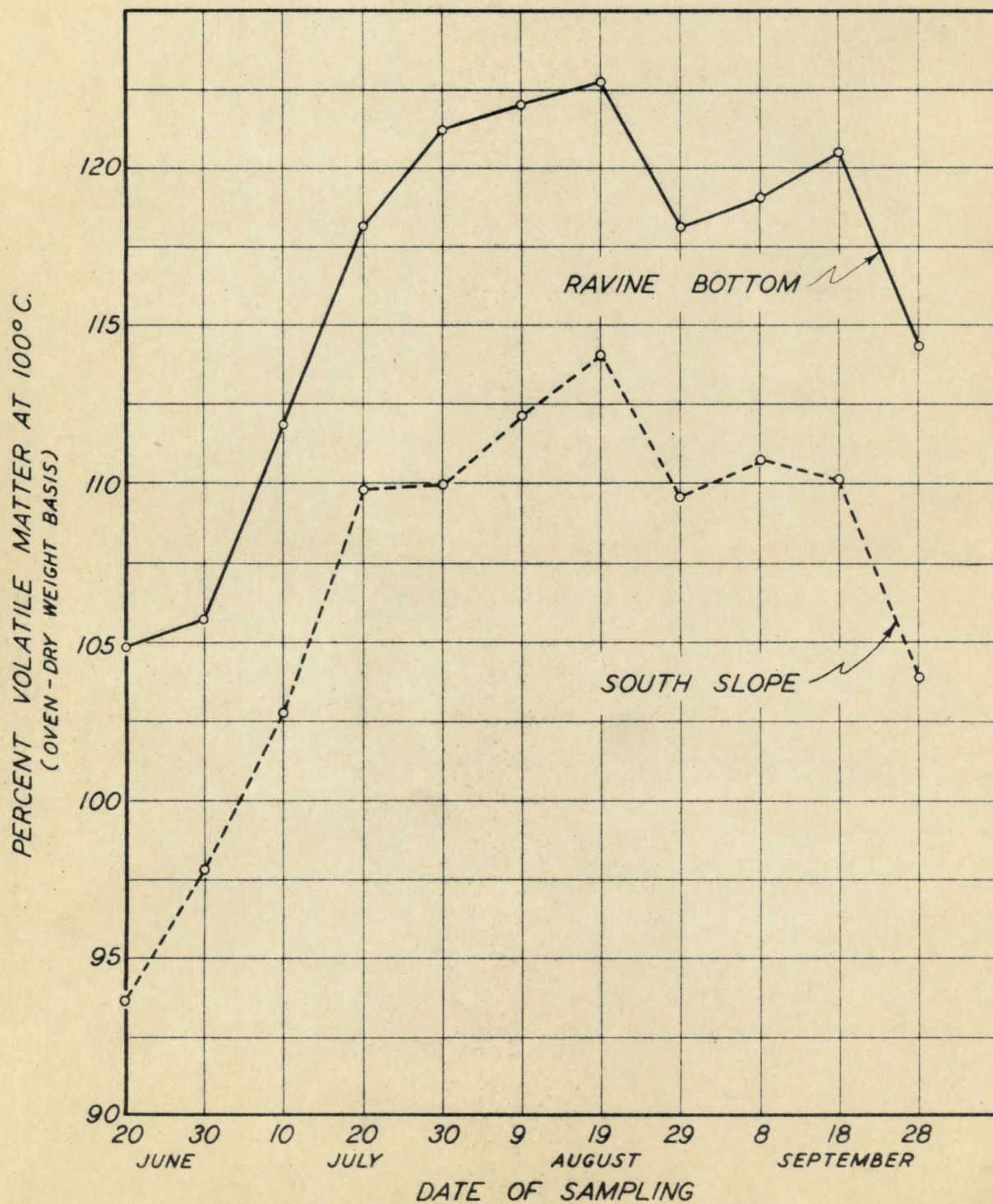
The selected trees were sampled by climbing and severing the tips of branches by means of a specially constructed pole and blade.

*How much*  
A suitable quantity of green needles was removed as rapidly as a twig was severed and placed in an air-tight container. These containers were weighed as soon thereafter as possible. Second- and third-year needles only were used so as to avoid the succulence of the first year's growth and the possible natural desiccation in the needles older than three years. Approximately an equal amount of needles was taken at each sampling.

Actual sampling began at the young-growth area on June 20; on June 21 at the south slope in the virgin area and on July 11 at the creek bottom in the virgin area. Sampling continued at regular 10-day intervals thereafter. The time of sampling was confined to the period between 1:00 p.m. and 5:00 p.m., attempting to sample each tree at approximately the same time in order to avoid any

*Don't 1st + 4th yr. needles have effect on fire?*

FIG. 1 - TREND OF VOLATILE CONSTITUENTS IN LEAVES OF  
*PINUS PONDEROSA*  
(YOUNG GROWTH AREA)



possible diurnal fluctuations. Needles were collected regularly for determination of their steam-volatile oil content after the study was thoroughly under way.

To supplement the data derived from the pine needles and to obtain some concept of the trends of the moisture content of the lesser vegetation, eight Ceanothus (Ceanothus velutinus) plants were selected for study after a fashion similar to that applied to the pine foliage. The sampling technique used for this broadleaf sclerophyllous shrub was similar to that developed for the trees. Four of the plants were located in a dry ravine and four on an exposed south slope. The first collection from Ceanothus was made on July 10 and continued thereafter at intervals of 10 days. Ceanothus was chosen for this study because of its relative abundance as compared to the rest of lesser vegetation and because it is not deciduous and could therefore be compared somewhat with pine.

Beginning July 10 soil moisture samples were taken at regular intervals of 10 days on each of the sites being studied. Three sets of samples were taken each time a collection was made, each sample representing one of three depths, 4 to 6 inches, 8 to 10 inches and 18 inches.

#### Laboratory Procedure

All samples were weighed to the nearest 10 milligrams immediately upon the completion of the collections and placed in an automatically regulated oven to dry at 100°C. for 12 hours. After that

Pretty weak reason for selecting C. vel. A rubber plant isn't deciduous either

I wonder why these depths were chosen?

I think 24 hrs. necessary to d.p. samples like these

period, they were reweighed, the loss in weight determined and this loss expressed as a percentage of the oven dry material.

To determine the quantity of steam-volatile oil contained in the needles, samples of pine foliage were submitted to steam distillation. This was accomplished by placing a known quantity of carefully chopped, fresh needles with a suitable quantity of water in a distilling flask and heating the flask over a sand bath. The steam generated was condensed, the distillate collected in a burette kept cold by ice; the volume of the oil layer measured and separated from the water; the specific gravity of it determined; and the yield of oil expressed as a percent of the fresh weight.

#### Results

Results of this investigation are presented largely in the accompanying figures.

Trend of volatile matter expelled at 100°C. for both of the sites represented on the young-growth area are shown in figure 1. As might be expected from the environment at the two sites, a distinct difference in the volatile content of the pine foliage is manifested. The most significant feature of figure 1, however, is that the curves for both sites exhibited a marked upward trend until the height of the summer season had passed. For the samples collected from trees in the bottom of the ravine this seasonal change varied from a low of 105 percent on June 20, to a high of 123 percent on August 19, or a range of 18 percent. For the samples drawn from trees on the south slope the values at corresponding times were 94 and 114 percent, or a range of 20 percent.

Inasmuch as the points plotted on the curve in figure 1 represent averages of samples taken from five trees at each location and at two positions on each tree, it is essential that these data be subjected to a statistical analysis for true tests of significance. A composite tabulation of the result of the analysis of variance is presented in table 3.

Table 3. Analysis of variance of leaf volatile content considering the variance due to date of sampling, position of leaves on the trees, site on which trees were growing, and individual trees

Variance Due to	: D.F.	: Sum of Squares	: Mean Square
Date	: 10	: 7,577.7794	: 757.7779
Position <sup>1/</sup>	: 1	: 629.7963	: 629.7963
Site	: 1	: 4,764.6722	: 4,764.6722
Between trees on same site	: 8	: 4,794.1082	: 599.2635
Interactions:			
Date-Position	: 10	: 181.2119	: 18.12119
Date-Site	: 10	: 60.1719	: 6.01719
Position-Site	: 1	: 0.2701	: 0.2701
Remainder	: 10	: 57.1522	: 5.71522
Error	: 168	: 2,279.3231	: 13.56859
Total (Series)	: 45	: 13,271.0540	: 308.62916
Total (runs)	: 219	: 20,344.6853	: 92.89811

<sup>1/</sup> Position refers to whether the needles were taken from the upper or the lower portion of the crown.

By use of the table of F values as given by Snedecor<sup>1/</sup> it is apparent that variance due to date of sampling, position of leaves on the tree, site on which the trees were growing and individual trees are all significant as compared to the variance due to error. Conversely the interactions of these variables are not significant when compared to either error or the remainder. Hence it is judged from this analysis that the variation in the data caused by each one of the above variables is real and not attributable to chance variation. It is significant also to note that the error of any plotted point in figure 1 independent of differences due to date of sampling, position, site and individual trees, is but  $\sqrt{\frac{13.56859}{10}}$  or 1.173 percent, indicating further the real significance of the volatile content of the leaves at any date of sampling.

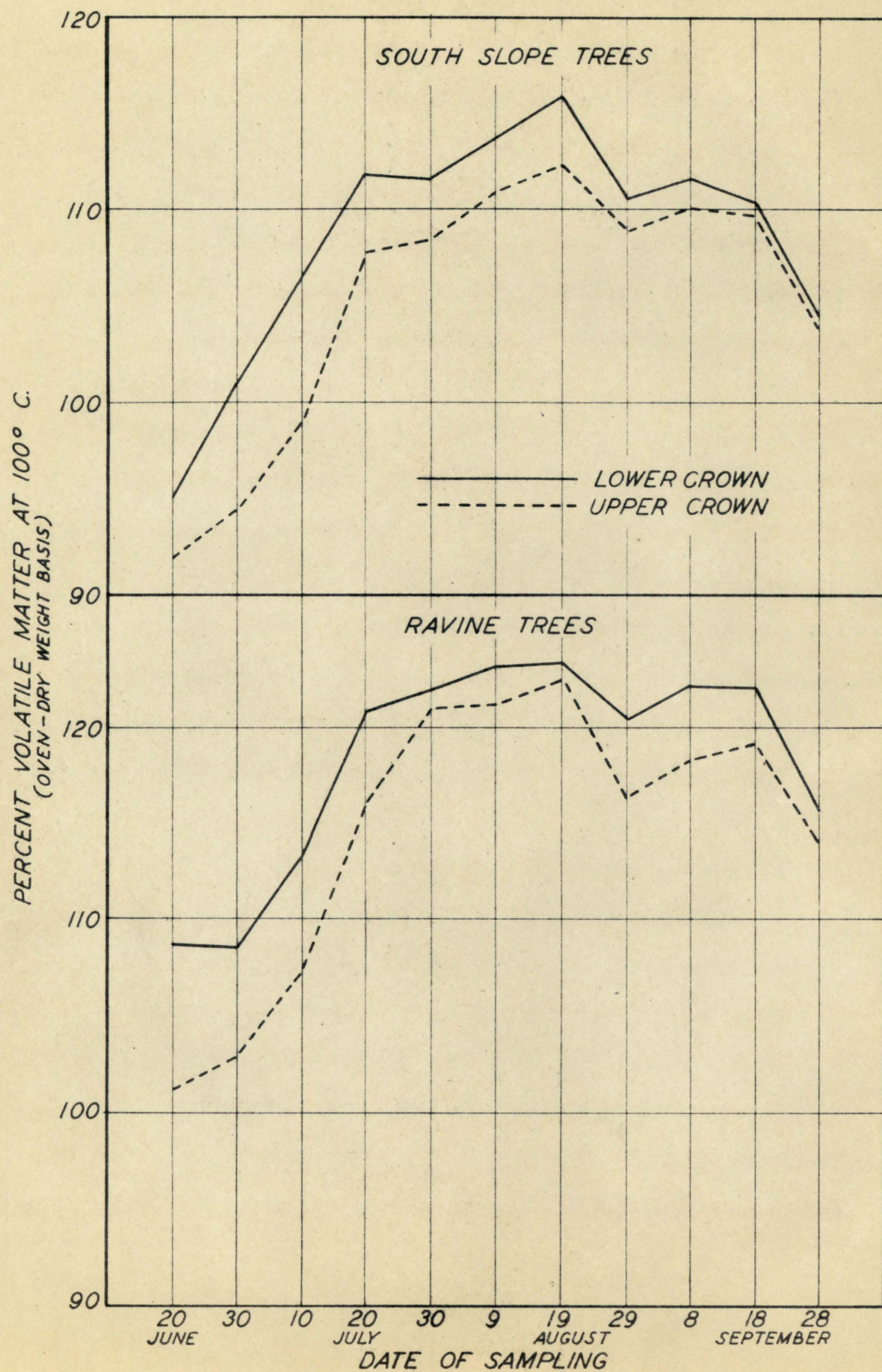
As a point of interest the samples were segregated on the basis of position on the tree (upper or lower crown) by periods (fig. 2). While the differences observed are not large, the trends are very consistent and the differences caused by position are real. The leaves in the lower crown in case of both sites have consistently more volatile matter than the leaves in the upper crown.

Samples of leaves of different ages on the same twig were taken so as to carry the investigation of the variations of volatile matter within individual trees still further. Leaves of the current year's growth were found to have the greatest content of volatile matter. This was followed in a somewhat regular declining order by 2-, 3- and 4-year-old needles. For example, a series of samples taken

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<sup>1/</sup> Snedecor, G.W., 1934. Calculation and Interpretation of Analysis of Variance and Covariance. Collegiate Press Inc., Ames, Iowa. 96 p.

FIG. 2 - SEASONAL TREND OF LEAF VOLATILE MATTER IN UPPER AND LOWER PORTIONS OF THE TREE CROWN.



about the middle of August, from a lower branch of a tree growing on south slope, gave the following percentages of volatile matter on an overdry basis: Current year's needles - 148.2 percent, 2-year-old needles - 121.8 percent, 3-year-old needles 116.2 percent and 4-year-old needles - 105.8 percent. Inasmuch as 2- and 3-year-old needles only were used in this study of seasonal trends it appears that a fair, though somewhat low average of all of the foliage in the crown was secured.

The seasonal march of soil moisture and air temperature is presented in figures 3 and 4. The soil moisture as shown in figure 3 represents the average moisture content of the surface 18 inches of soil. The wilting coefficient of the slope soils was reached prior to July 10 while the corresponding figure for the ravine soils was reached on July 10. At no time during the course of the study did the soil moisture at either location rise above the wilting point. There was but .18 inch of precipitation during the entire period and that occurred in one storm on July 30.

There is no contention that the soil moisture around the roots of the trees below the 18-inch level was the same as that above the 18-inch level. However, in view of the geologic formations and lack of ground water, it is reasonable to assume that very little water was available for consumption by the trees and that the seasonal march of volatile matter in the pine needles did not follow the march of soil moisture. That volatile content of the pine needles does not follow the march of soil moisture is illustrated by the fact that there was

FIG. 3 - MEAN MAXIMUM & MINIMUM TEMPERATURES  
(BY TEN-DAY PERIODS)

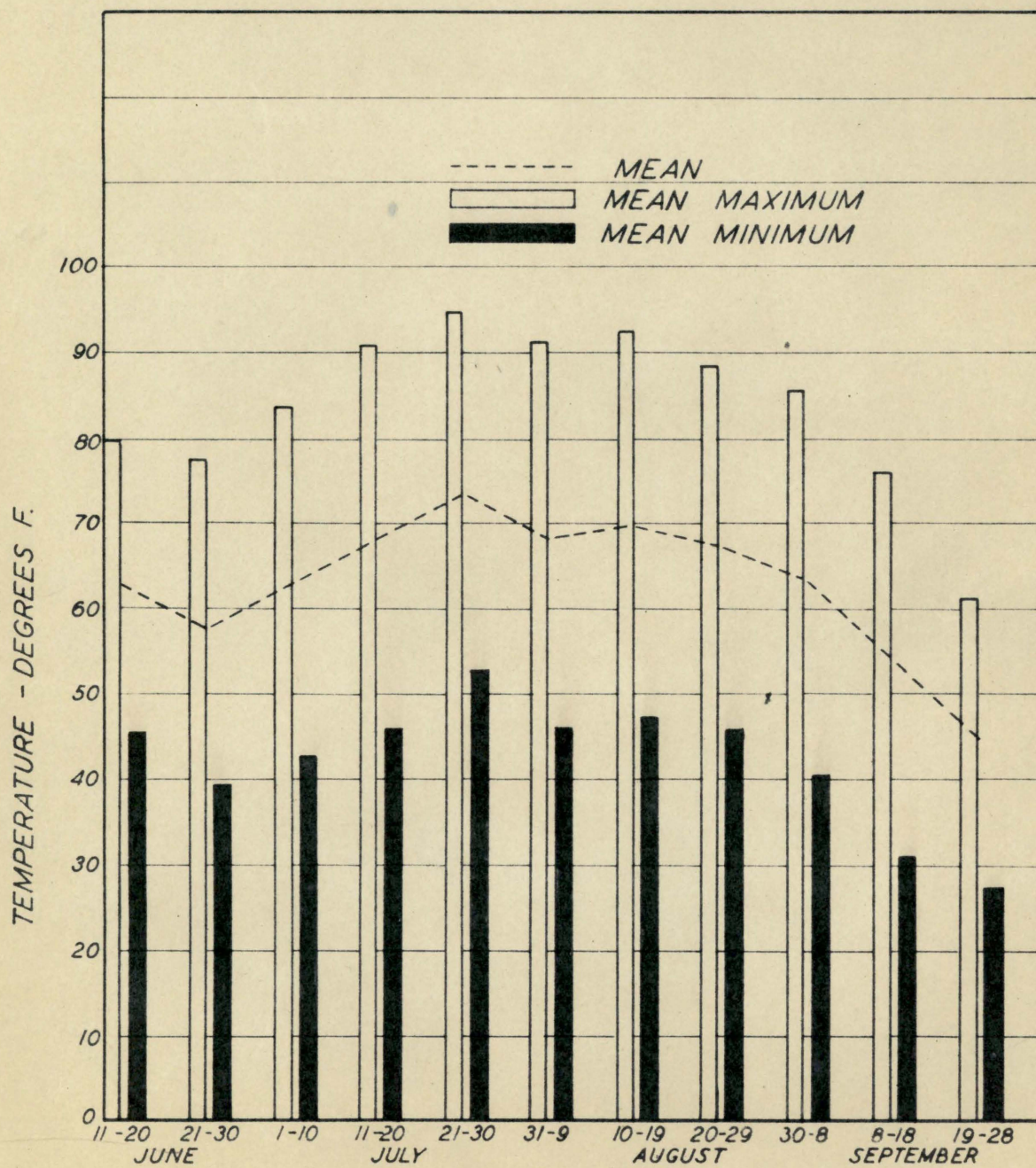
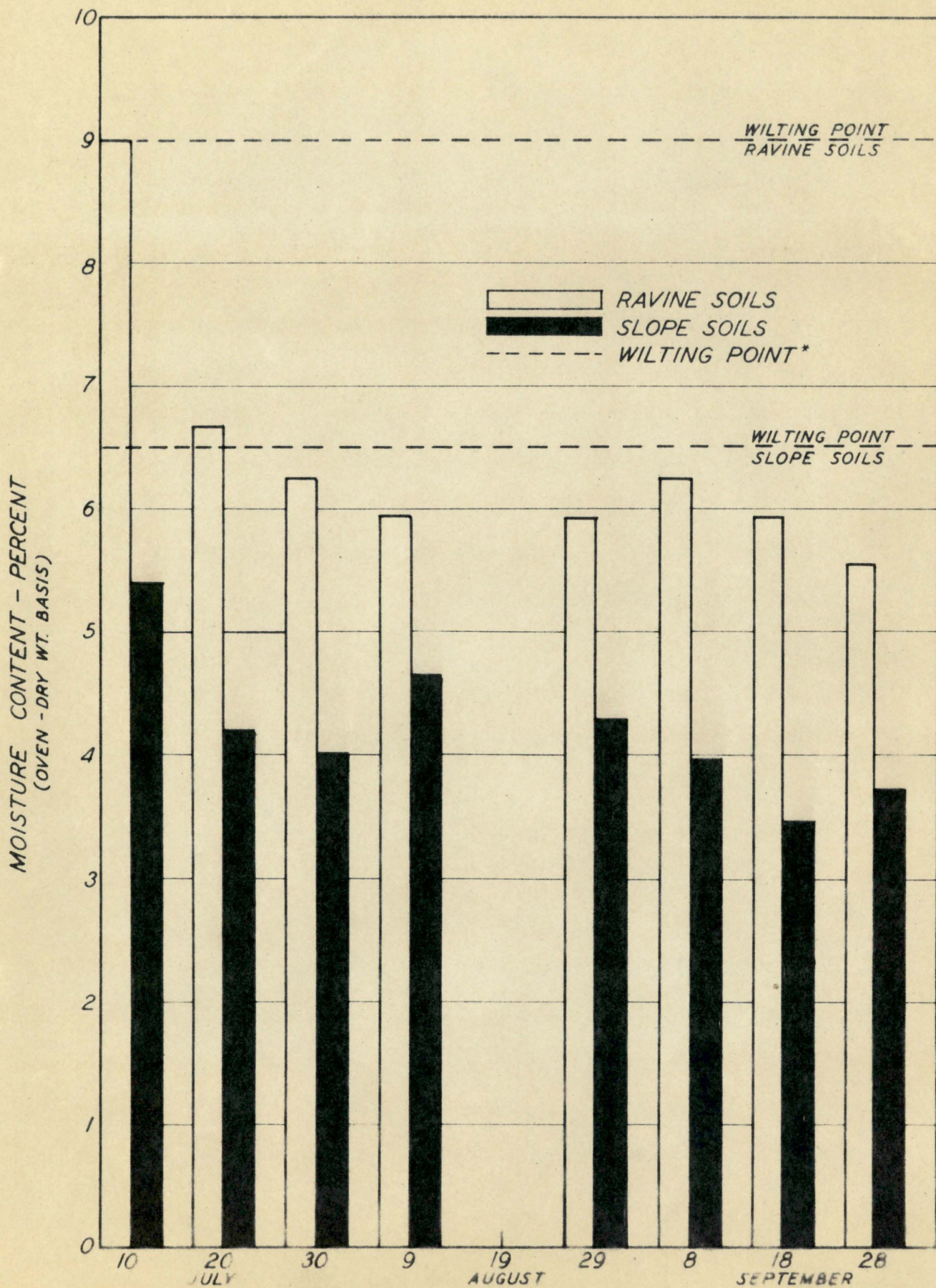


FIG. 4 - SOIL MOISTURE & DATES OF SAMPLING



\* WILTING POINT DETERMINED BY BRIGGS & SCHANTZ'S METHOD

a steady advance of the volatile content of the leaves until August 19, and thereafter a steady decline. During 10-day periods in which this reversal took place there was no precipitation and presumably no marked change in ground water which could account for the observed fluctuations.

??  
No connection  
at ground  
water

Air temperature, on the other hand, seems to be related somewhat to the seasonal march of volatile constituents. Prior to the period July 21 to 30 the air temperature rose steadily as did the volatile content of the pine needles. The air temperature, both mean and maximum, began to decline after this period. The volatile constituents of the needles increased until August 19, and thereafter began to decline thus indicating that there may be either a real or an apparent association between the two trends. Fluctuations from period to period are not definitely associated, but there is a possibility of enough lag in physiological functions of the tree so that variations in volatile matter could not be expected to follow variations in temperature except on the basis of general trends.

Only the trees in the young-growth forest have been discussed thus far, but as mentioned previously, trees were also sampled in a virgin stand. Figure 5 presented the trend of the volatile content of the pine needles taken from trees on a south slope and trees near a stream in the virgin forest. It is noted that the trend observed from the samples taken on the south slope closely follows and substantiates the trends in the young-growth timber, but the samples drawn from trees growing near a live stream whose roots presumably had access to free

FIG.5 - TREND OF VOLATILE CONSTITUENTS IN LEAVES OF  
*PINUS PONDEROSA*  
 (VIRGIN TIMBER AREA)

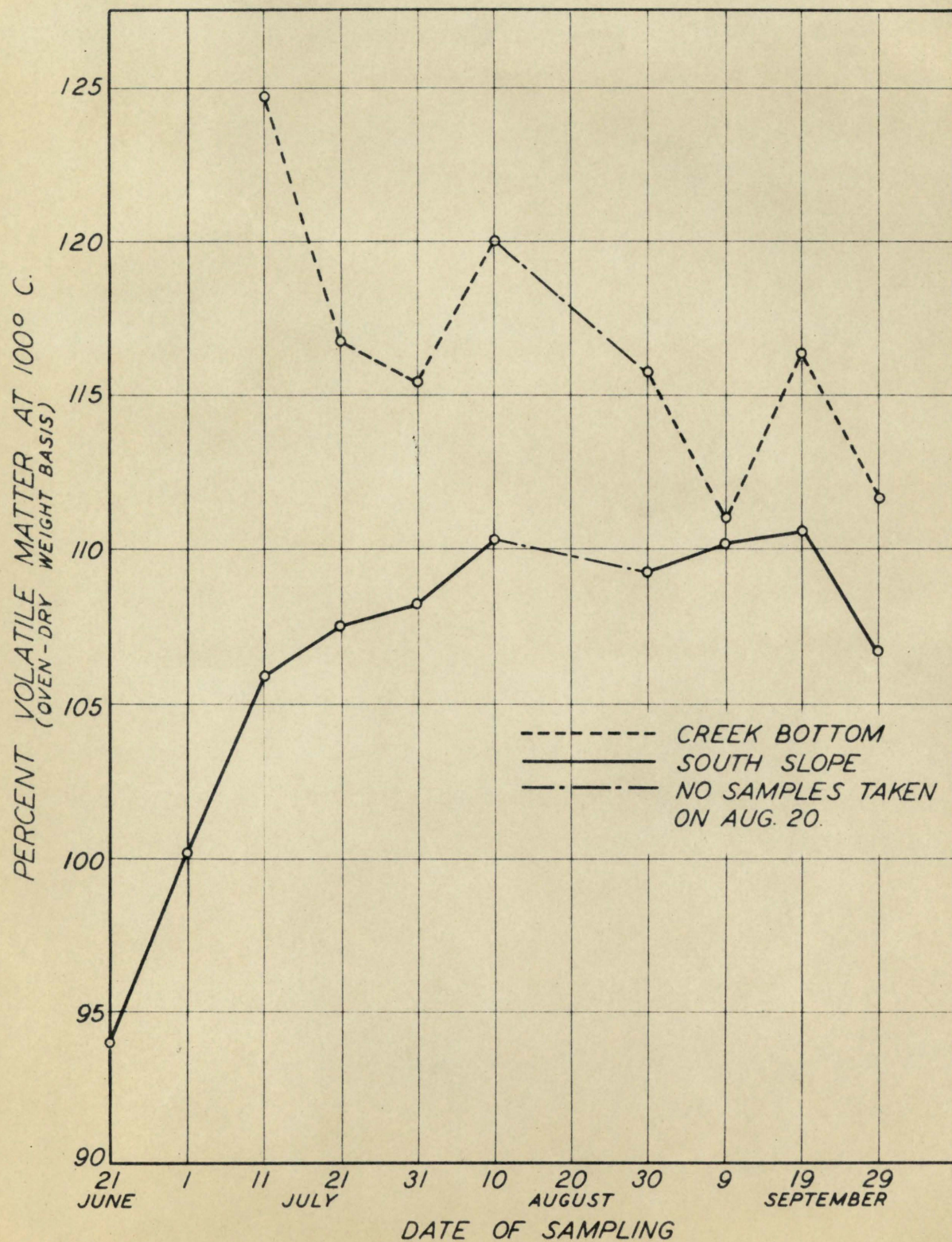
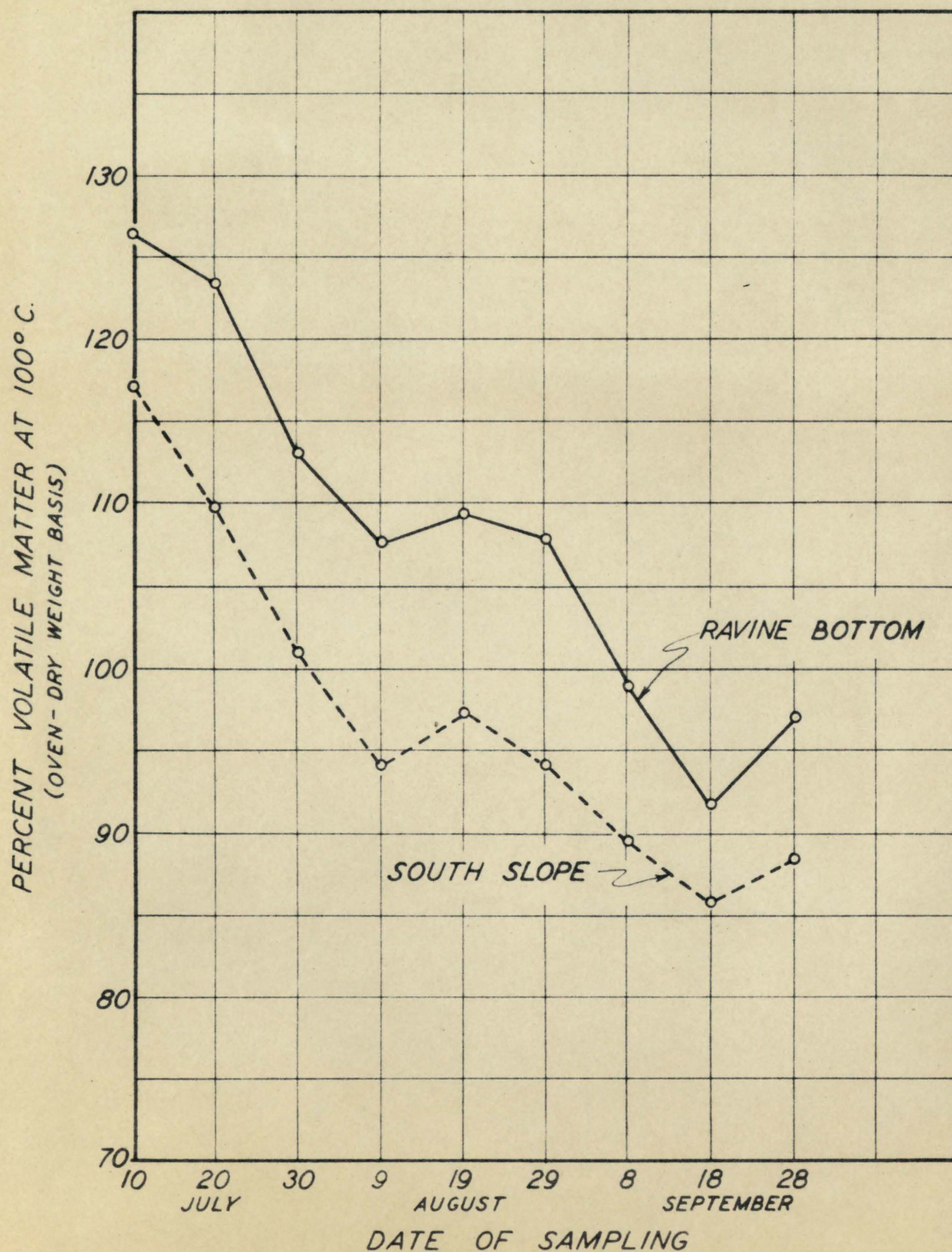


FIG. 6 - TREND OF VOLATILE CONSTITUENTS IN LEAVES OF  
*CEANOOTHUS*



Steam distillation of pine needle samples to determine volatile oils are too meager to establish possible trends. The major part of this phase of the work was largely preliminary in character, as the necessary refinements for a quantitative determination of the oil content were not introduced until late in the season. Two features were quite well established by these determinations, however, namely that no extreme fluctuations in the oil content of the pine needles occurred, and that at any one time the percentage content of oil in the needles was very small. A 200-gram sample of fresh needles produced on the average about 0.75 c.c. of oil (measured at 4° - 8°C.) with a specific gravity of about 0.8, or a percentage yield of about 0.30 percent on a fresh weight basis. As high a yield as 0.41 percent was noted in one case. Fluctuations in volatile oil content cannot account even partially for the major trends observed in the pine needles according to these results.

In the case of *Ceanothus* leaves volatile oils comprised even less of the total volatile constituents than in the case of pine needles. For example, in one distillation of 150 grams of fresh *Ceanothus* leaves 0.15 c.c. of oil was produced.

#### Discussion

Before attempting to analyse the data presented, it is necessary to emphasize that the volatile matter expelled from the leaves at 100°C. is not comprised wholly of water. It is possible to say with a fair degree of certainty, however, that the only other constituent volatilized to any extent at that temperature is the terpenes.

As shown, terpenes do not constitute a significant weight fraction of the needles. This obviates the possibility of tracing the major fluctuations in the volatile constituents to the presence of terpenes. It is quite reasonable to assume, therefore, that the trends indicated in the accompanying graphs can be ascribed chiefly to apparent or actual change in water content. The term "volatile matter" notwithstanding has been used exclusively in preference to the term "moisture" to convey the idea that the writers were cognizant of the fact that water was not the only substance involved in the volatilization.

The most striking phenomena in regards to these data are not that they show definite trends for the most part, but that the moisture content of the pine foliage, instead of decreasing as the season advanced, actually increased and reached the peak when drought stress was most acute, and fire hazard was the highest. This appears somewhat anomalous when it is considered the foliage becomes generally more lignified and less hydrated with age as brought out in this report. However, as these data are expressed necessarily on a percentage basis, this increase may be either apparent or actual. If it is apparent, the absolute moisture content can remain essentially constant, but dry weight must decrease. On the other hand, if it is actual, the dry weight can remain constant or even increase, but there must be a disproportionate variation in absolute moisture content.

A decrease in dry weight or a disproportionate increase in absolute moisture content on the basis of our present knowledge is difficult to explain. It is permissible to postulate, of course, but

it must be remembered that any forthcoming explanation is necessarily a matter of conjecture until further intensive studies can be pursued.

If a decrease in dry weight does occur, it might take place under the following circumstances. From the observations on soil moisture it was noted that little or no water was available to the trees. This lack of moisture would tend to materially decrease the processes of assimilation in trees, either by lack of sufficient water for proper physiological functions or by causing the stomata to either close or be plugged by a resinous or waxy exudation, both of which would hinder gaseous exchange. If gaseous exchange is reduced, assimilation necessarily decreases. This decrease in assimilation may proceed to a point where the net production of assimilates falls below the quantity used in respiration and various polysaccharides, pentosans, pectic substances or other dry-weight constituents stored in needles are broken down and either translocated or expelled with water and volatile oil during the process of drying. It is necessary to assume in this connection that water loss from the stomata is not proportional to gaseous intake, if respiration is aerobic; or that the stomata are closed or blocked sufficiently to hold volatile products of respiration such as alcohol and water, if respiration is practically anaerobic. In many respects this somewhat hypothetical explanation seems plausible, but when it is considered that the trend of volatile constituents in the needles began to change in midsummer without the benefit of any significant change of soil moisture, the basis of the postulation is questionable.

Should an increase in the absolute water content of the foliage actually take place, it is possible to resort to a slightly less fantastic scheme to account for the trends observed. During periods of extreme drought, there may be a marked increase in some of the more complex carbohydrates, such as the polysaccharides and pentosans. This increase may be merely a response of the tree toward the elaboration of hydrophillic colloids which can bind water against forces of transpiration and which can aid in building up a suction pressure to draw water from other parts of the tree. Similar food conversions have been noted and associated with frost resistance in several northern conifers, and it seems likely that drought resistance may follow this course resulting in a high bound water content of the foliage. To substantiate this conjecture somewhat the data for the last collection of samples is cited. All samples in this case showed a marked decrease in moisture content. For the 10-day period prior to this sampling date the temperature reached a low for the period of the study, with a mean of 44°F., a mean maximum of 61°F., and a mean minimum of 27°F. Associated with the decrease of the moisture content, this decrease of temperature can be explained by assuming that the lower temperatures induced certain food transformation, which reduced the amount of hydrophillic colloids and consequently the amount of water "bound" against forces of transpiration. A general though not entirely consistent relationship, appeared to exist throughout the study in that as temperature increased moisture content increased and as the temperature declined the moisture content followed in the same order.

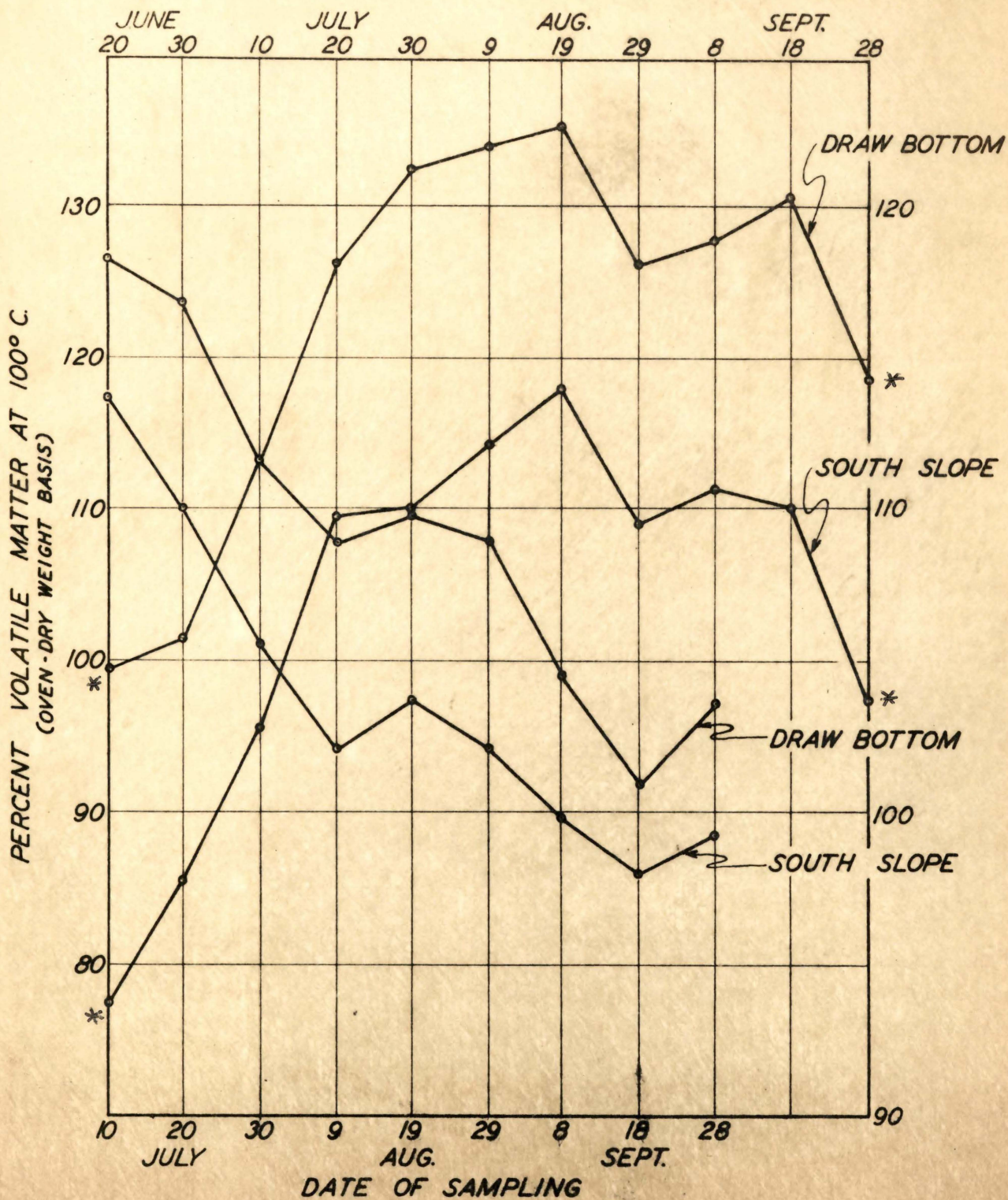
The uncertain behavior of the trees in the virgin stand growing on the banks of a live stream, as well as the behavior of the *Ceanothus* remains to be explained. As stated in an earlier paragraph the trees growing near the live stream presumably had access to free water at the deeper soil levels. Consequently, if these trees had the possible advantage of ample free water there would be a basis to assume that they did not experience a critical period of drought stress and that their foliage would have a tendency to exhibit a characteristic dehydration curve as the season progressed. Although the data are not strictly conclusive on this point, there is evidence which supports this hypothesis (fig. 5). The trend of moisture content generally appears to be downward.

The behavior of the samples taken from the *Ceanothus* bushes is essentially normal. The general dehydration of the foliage with the advance of season is plainly marked in figure 6. Foliage from plants growing at the bottom of a ravine manifested the greatest degree of hydration throughout season as in the case of foliage for the pine trees. This difference can be attributed to the larger amount of available moisture in the ravine to less evaporation stress as well as to the greater succulence of "shade leaves" in the ravine as opposed to the "sun leaves" of the south slopes.

#### Summary

A study of the trend of the moisture content of evergreen foliage was made to ascertain the factors associated with extreme inflammability of forest fuels. This investigation has progressed

TREND OF VOLATILE CONSTITUENTS IN LEAVES OF  
PINUS PONDEROSA & CEANOTHUS VELUTINUS  
SLAUGHTERHOUSE GULCH, IDAHO.  
-1934-



for one year and although the results are preliminary and the explanations for the phenomena encountered somewhat nebulous, it is felt this report is warranted so as to invite additional work as well as constructive comment.

The volatile content of ponderosa pine foliage, either real or apparent, was found to be comparatively low in late spring. The content approximated 93.6 percent for young-growth trees growing on a south slope, 104.9 percent for young-growth trees growing in the bottom of a dry ravine, and 94.1 percent for old-growth trees growing on a south slope. Leaf samples were taken also from trees growing on the banks of a live stream in the old-growth stand. The first results were secured 20 days after the work was undertaken on the other sites and at that time the volatile content of the foliage was 124.7 percent. As the season progressed the volatile content of the foliage increased until midsummer when it reached a peak of 114.1 and 122.7 percent in the young stand on the south slope and in the bottom of the dry ravine, respectively. The corresponding data in the virgin stand were not secured at this time. The volatile matter in the foliage decreased somewhat irregularly after midsummer until the study was brought to a close near the end of September.

The foliage from trees growing on the most severe sites were found to have the lowest volatile content, although seasonal trends were similar regardless of site, with the exception of those trees that were thought to have access to free water. Variations in the volatile content of the foliage associated with site, date of sampling,

water have a distinctly different trend. It appears that there is a steady though somewhat irregular decline in volatile content of the needles in the latter case throughout the summer. This fact indicates that drought is associated with the observed trends and that if a ponderosa pine tree is furnished an excess of water there will be a decline in the volatile matter in the needles during a period of drought stress.

A comparison of the trend of volatile constituents in Ceanothus leaves, as presented in figure 6, to the trends in the pine needles furnishes some interesting data. Ceanothus in all probability has a conduction system, water requirements, temperature equilibria of chemical reactions and other features quite unlike that of ponderosa pine, their main point of similarity being that both are evergreen species. Regardless, however, of either their similarity or dissimilarity of physiological or anatomical features, the downward trend throughout the summer of the volatile constituents in the Ceanothus leaves is distinctly different from that experienced in the pine needles. The volatile content of the Ceanothus leaves ranged from a high of 127 percent on July 10 to a low of 92 percent on September 18 for the plants growing on a south slope and from 117 percent to 86 percent on corresponding dates for plants growing in the bottom of a dry ravine. It is of significance to note, however, that the influence of site on the volatile content of both Ceanothus leaves and pine needles is similar, the samples taken from the plants on the slope being consistently lower throughout.

Turned  
around  
according  
to figure  
6

position of sample on the tree and individual trees on the same site were all found to be real as compared to the error of sampling.

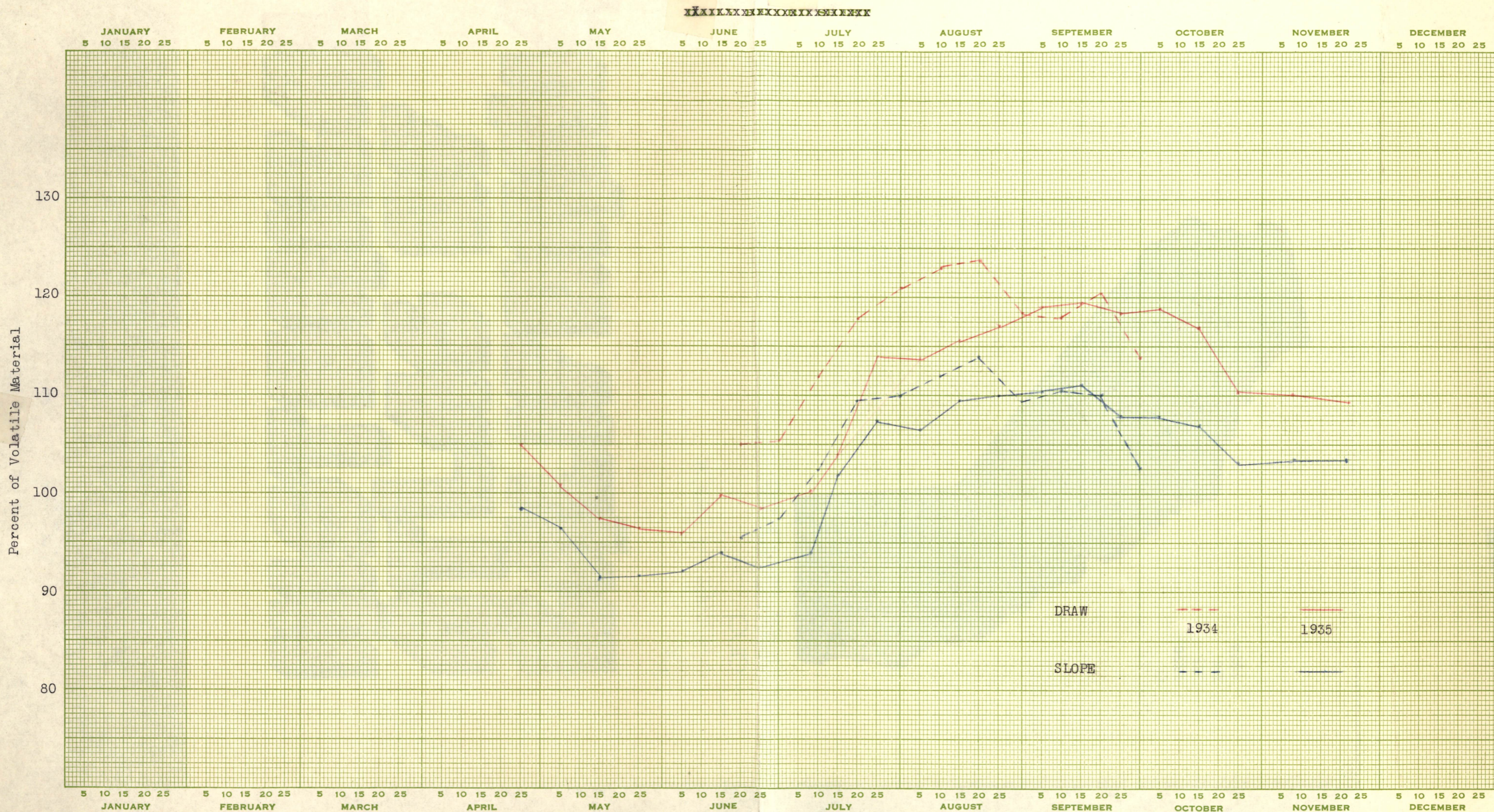
No consistent trend could be noted in the relatively small quantities of volatile oil in the pine foliage.

The degree of hydration and age of the pine needles were found to be associated.

The trend of the volatile constituents in the foliage of *Ceanothus*, an evergreen sclerophyllous shrub, was downward throughout the season. The shrubs growing in the more sheltered locations had a consistently higher degree of hydration than those growing under exposed conditions.

While the relation of the volatile content of evergreen foliage to fire hazard is by no means solved, the investigations to date have raised many important fundamental problems in the way of clues that require extended research under field conditions.

# TREND OF VOLATILE CONTENT OF PONDEROSA PINE NEEDLES



6

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HTB

UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICE  
NORTHERN ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

ADDRESS REPLY TO  
SUPERINTENDENT  
PRIEST RIVER EXPERIMENTAL FOREST

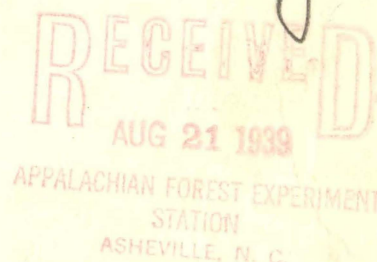
AND REFER TO  
RS-NRM  
Pf-2, B-5  
Vegetation



PRIEST RIVER, IDAHO

August 17, 1939

Mr. Geo. M. Jemison  
Appalachian Forest Experiment Station  
Federal Bldg.  
Asheville, N.C.



Dear George:

In accordance with your memo of August 12 I am enclosing the Connaughton - Maki report of June 10, 1935 on "Trends of the Volatile content of evergreen foliage - - -." No rush in returning but we would like to have this copy in our files later on.

Congratulations on the new arrival and we all hope that Bea is doing well.

Sincerely

Gris

H.T. GISBORNE

Enclosure

3/17/43

Gis: Looks like I took you  
at your word. Many thanks.

Gris